GLACIAL GEOLOGY OF AN AREA IN EAST CENTRAL ALBERTA

L.A.BAYROCK

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ABSTRACT

The Coteau ice advance boundary was mapped in the eastern part of east central Alberta and it was found that the Coteau moraine is located from 10 to 20 miles east of the terminal Coteau ice advance boundary. The glacial sequence of the area was established and it is comprised of a basal Grey till, the Viking till, and the Coteau till.

Mineralogical and mechanical analysis made on the Viking and the Coteau tills indicate no major break in the composition of the two tills. The individual soil profiles of the two tills did not reveal any appreciable weathering of silicates in the upper soil horizons. It was noted that the depth of leaching of the carbonates in the areas covered with the Viking till and the Coteau till is very similar and averages 23 inches.

The conclusion based on the laboratory investigation of samples of the Viking and the Coteau tills is that the time interval separating the two glaciations is quite short.

FRONTISPIECE

Coteau Ice Advance Boundary (solid line).

Location: Tp. 49, R. 2-west of the fourth meridian,

Sec. 26, SW corner, looking east.

THE UNIVERSITY OF ALBERTA

GLACIAL GEOLOGY OF AN AREA IN EAST CENTRAL ALBERTA

A DISSERTATION

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BY

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INTRODUCTION

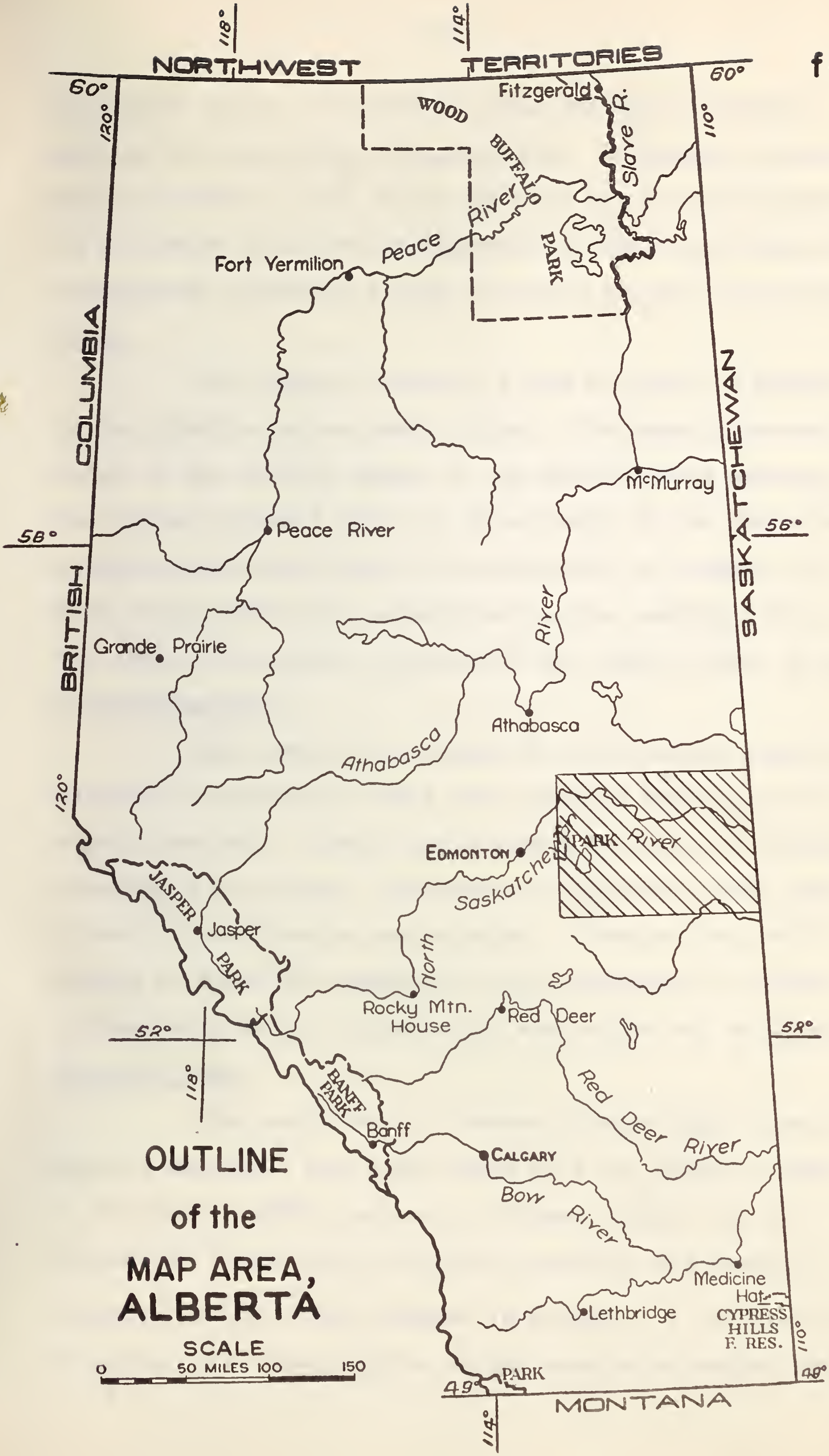
General Statement.

During the summer of 1953 a survey of glacial deposits of an area in East Central Alberta was undertaken by the author under the auspices of the Research Council of Alberta . The purpose of the survey was to outline the limit of the last ice advance in Alberta and also to establish the glacial sequence of the region.

There are two moraines present in the area; the Viking moraine, and the Coteau moraine. The Coteau moraine represents deposits from the last glacier to enter Alberta from the Keewatin center. The relative thickness of the till cover of the area is greatest in the morainic belts and thinnest between them. Three different tills were recognized; a Grey basal till, the Viking till, and the Coteau till.

Different lines of approach were applied in solving the problem of the position of the Coteau ice advance boundary. The banks of the North Saskatchewan River were inspected with the purpose of locating sections of glacial deposits. Tests on the depths of leaching of carbonates were taken in order to find a break between the Viking and the Coteau glaciations. Finally, aerial photographs, topographic maps, handspecimen variations of the two tills, depth of till cover, drainage pattern, and many other features and properties were incorporated into mapping the Coteau ice advance boundary.

Mechanical and mineralogical analyses were made on soil profiles from the Coteau glaciated region, the Viking


NORTHWEST TERRITORIES
BRITISH COLUMBIA
SASKATCHEWAN
MONTANA
WOOD BUFFALO PARK
Fitzgerald
Slave R.
Peace River
Fort Vermilion
McMurray
Peace River
Grande Prairie
River
Athabasca
Athabasca
EDMONTON
PARK
River
Saskatchewan
North
JASPER PARK
Jasper
Rocky Mtn. House
Red Deer
Red Deer River
BANFF PARK
Banff
CALGARY
Bow River
Medicine Hat
Lethbridge
CYPRESS HILLS F. RES.
PARK
OUTLINE of the MAP AREA, ALBERTA
SCALE
0 50 MILES 100 150
60°
58°
56°
52°
49°
120°
118°
114°
110°
fig. 1

Rutherford and placed it farther to the west. The latest work on the area by P. S. Warren (1944) places the Coteau boundary in the same position as Rutherford. The boundary of the Coteau moraine as shown by Rutherford and Warren agrees with the author's field mapping. The only remark that might be added at this point is that the limit of the Coteau ice advance is marked not by the moraine but rather by glacial deposits which occur to the west of the moraine.

The northern part of the Coteau moraine as mapped by Bretz (1943) coincides with the position of the Viking moraine shown by Warren (1937) (1944). The only place where Warren and Bretz agree is on the position of the southern part of the Viking moraine in the area mapped by the author. This difference of opinion on the position of the Coteau moraine is due to the fact that Bretz (1943) probably mapped bedrock expressions as moraine and further mistook the northern part of the Viking moraine for the Coteau moraine.

PHYSIOGRAPHY

The area mapped is divided into three major physiographic divisions; first, the area covered by the Coteau ice advance, second, an area of bedrock expression in the vicinity of Vermilion, and third, the Viking moraine area.

Coteau Glaciated Region.

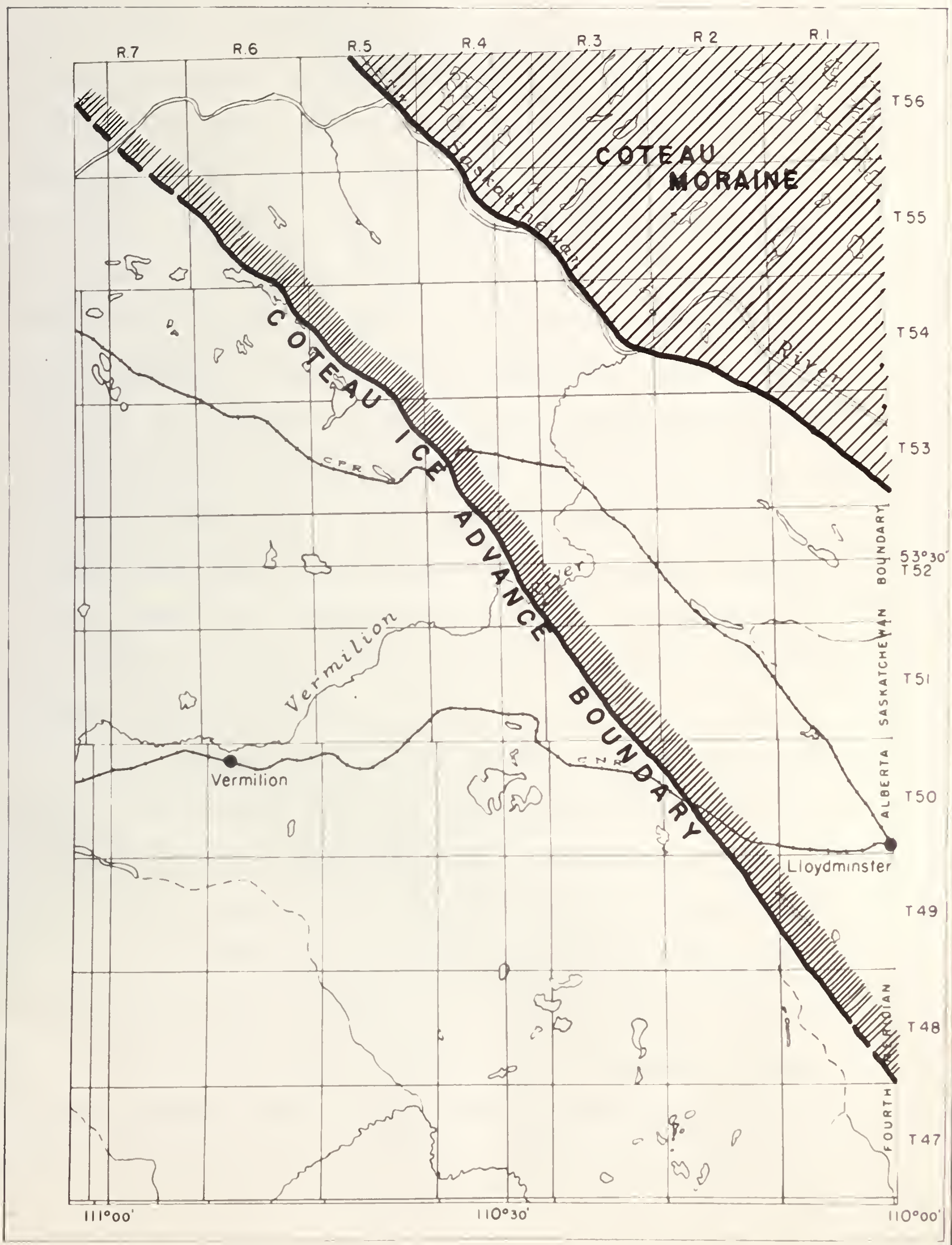
The Coteau glaciated area can be subdivided into the Coteau moraine and the region between the terminal Coteau moraine and the terminal Coteau ice advance boundary (fig. 2). The terminal Coteau ice advance boundary does not coincide with the terminal Coteau moraine as the moraine is found about 10 to 20 miles east of the outer border of the ice advance. The part of the Coteau glaciated country between the moraine and the terminal ice advance boundary shows many stagnant ice features, and is quite flat as compared to the typical morainic topography of the Coteau moraine itself.

The Coteau terminal moraine has an indefinite border on the west and continues to the east into Saskatchewan beyond the fourth meridian. The topography of this area is hilly. The hills are nobby with steep sides and sometimes have more than one peak. No definite trend to the hills was noted. Many undrained lakes occupy larger depressions and are fed by small creeks which drain the surrounding country. The uneven skyline of the moraine can be seen on plate 6 A.

The region between the terminal Coteau moraine and the terminal Coteau ice advance boundary has very little relief as compared with the Coteau moraine and the bedrock topography west of the boundary. The southern part of this region is

fig. 2

Diagram showing
the COTEAU MORAINE
and
the COTEAU ICE ADVANCE BOUNDARY



characterized by the presence of a large number of north-easterly trending ridges some of which were suggested by J. A. Allan (1944) to be eskers.

They are composed of essentially the same till as the surrounding country but are perhaps a little more sandy in places. No stratification or lamination has been observed in them. These ridges average from 15 to 25 feet in height, 50 to 80 feet in width, and a mile or more in length (plate 7 A and B). R. E. Deane (1950) has described similar ridges in the Lake Simcoe district, Ontario, and believes that they are ridges of till deposited between large stagnant ice blocks. West of these ridges and approaching the border of the Coteau ice advance, the ridges become more obscure and numerous kettle holes take their place. The kettle holes first appear at the terminal ends of the ice block ridges and become more abundant to the west. Finally they form a kame like structure at the edge of the Coteau glacial advance boundary. This is well illustrated by aerial photographs (plate 1).

The northern part of the Coteau ice advance area has no ice block ridges, but has broad flat ridges parallel to the Coteau boundary which may mark short halts of the retreating Coteau glacier. It is difficult to observe these ridges from the ground but they show up on aerial photographs and on topographic maps (plate 2). They are up to a mile in width, several miles long and 50 to 100 feet high. Coulees which occur between these ridges are also parallel to the ice advance boundary.

The western edge of the Coteau till is not marked topographically and in some places cannot be recognized from the ground. The boundary of the Coteau glaciation north of the Vermilion River follows more or less the outcrop line of the Ribstone Creek and Brosseau sandstones. The Coteau ice advance area itself is located in the Lea Park outcrop area. The above mentioned sandstone members resisted glacial erosion and resulted in the surface bedrock expressions of the Vermilion area. On the other hand the shale of the Lea Park formation was probably more susceptible to glacial erosion and hence was planed to form the flat country of the terminal Coteau glaciated region. South of the Vermilion River the Ribstone Creek and the Brosseau sandstones outcrop in an approximate east-west direction. In this area there is no change of topography at the terminal Coteau ice advance boundary.

The trend of the Coteau boundary is approximately N 40°W in the area mapped. The trend of the Viking glaciation is more or less north-south. These two trends further help to distinguish the two glaciations. Aerial photographs showing the margin of the Coteau glaciation illustrate this point (plate 1). The trends of the two glaciations influence the drainage pattern of the country. Warren (1944) in discussing the influence of glaciations of the drainage pattern in Alberta writes that the north-south trend of the Viking glaciation turned the North Saskatchewan River from its north-east course to an easterly course and that the Coteau moraine undoubtedly is responsible for establishing

a southeasterly direction for the North Saskatchewan River. The author would agree with this interpretation and add that the trend of the North Saskatchewan River in the area of the terminal Coteau ice advance west of the moraine reflects short halts of the retreating Coteau glacier.

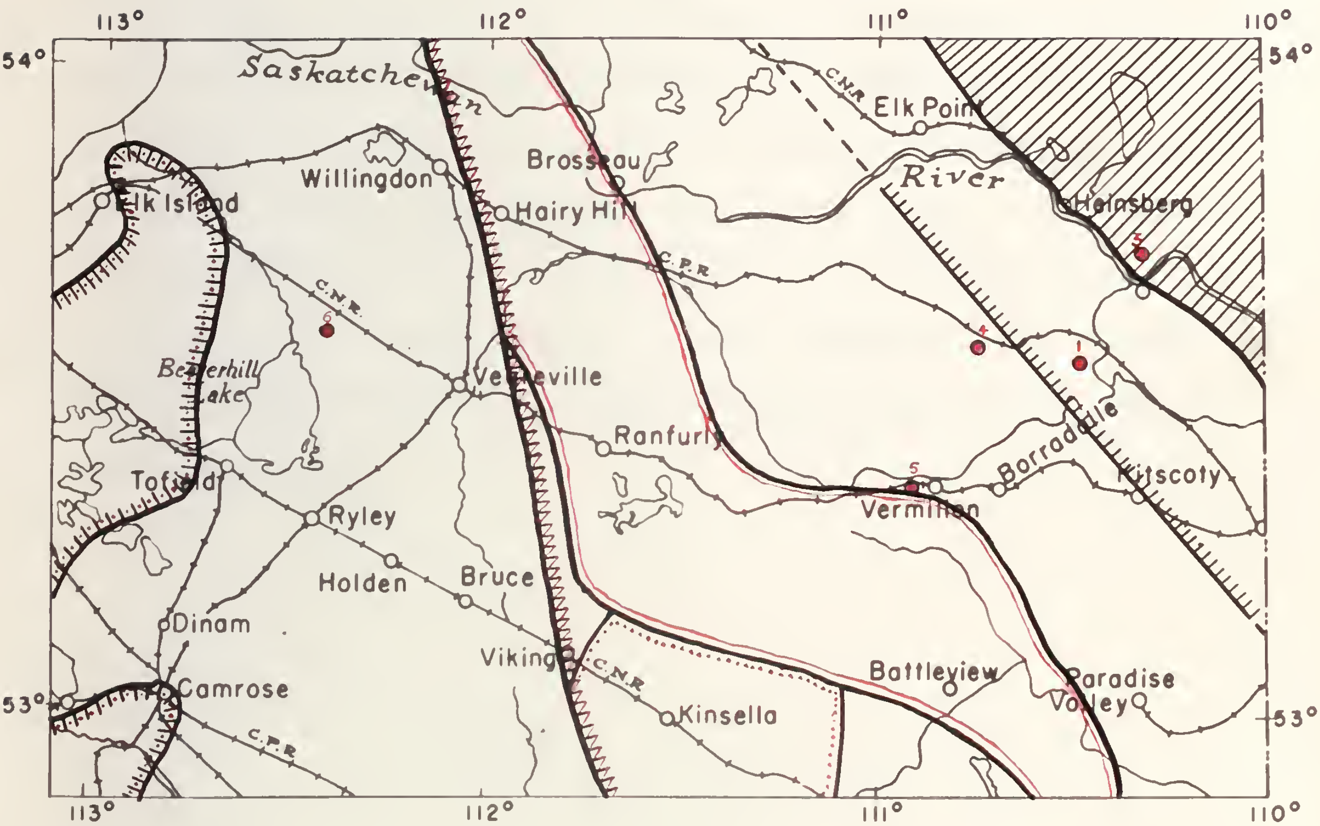
Vermilion Bedrock Expression Area.

The eastern margin of this area is defined by the boundary of the Coteau ice advance. On the west the border of this area is not well defined but grades into the Viking moraine. The general topography of this region is hilly and these hills are quite different from those in the Coteau moraine. The hills of the Vermilion bedrock expression area have gentle slopes and do not have any sharp breaks. No trend to the hills was noted from the ground but an east-west trend is evident from the aerial photographs (plate 1). Sloughs and lakes of this area are usually much larger than those found in the Coteau moraine.

The till cover of this area is thin and many road-cuts show exposures of bedrock covered with a thin layer of till. At a few localities severe contortions in the bedrock were observed which probably were produced by the pressure of the overriding glacier. Hopkins (1923) observed similar structures in the area of Mud Buttes in Alberta and postulated that they were the result of glacial pressure and shearing. Plate 8 shows such a roadcut which exposes the contorted bedrock. It was noted in the field that only the clayey bedrock showed such contortions. From the evidence gathered in the field it is suggested that the topography of this region

fig. 3

POSITION OF MORAINES
IN MAP AREA



Buffalo Lake Moraine

Viking Moraine

Coteau Ice Advance Boundary

Coteau Moraine

Coteau Moraine (Bretz, 1943)

Viking Moraine (Bretz, 1943)

Location of Sample Profiles

is controlled by bedrock expressions which have been modified by the overriding ice.

The Viking Moraine Area.

The outline of the Viking moraine as mapped by Warren (1937) is shown on fig. 3. True morainic character is evident in some places but at other localities where there are only broad hills, bedrock outcrops were noted in a number of roadcuts. Such bedrock outcrops were observed in some newly made roadcuts along Highway Number 16. From the above it is evident that the Viking moraine topography is partly controlled by bedrock expressions in certain areas. Many east-west spillways cut the Viking moraine in the Willingdon district. The western border of the Viking moraine is much better defined than the eastern boundary and can be mapped more accurately.

LITHOLOGY OF BEDROCK AND GLACIAL DEPOSITS.

BEDROCK

The bedrock of the area is composed of Upper Cretaceous sediments both marine and nonmarine, which are chiefly sandstones and shales. The bedrock is weakly consolidated, however, locally it is sufficiently lithified to form cliffs.

The composition of the tills is generally related to the nature of the underlying bedrock. Consequently, a full understanding of the lithology of the bedrock is necessary in order to make an intelligent appraisal of the variations in the tills of the area.

Table of Formations.

Recent. Windblown sand and loess; muck and bottom land.

Pleistocene.

Coteau till	Light brown to yellow-brown, sandy to clayey till.
Viking till	Light brown to dark brown, clayey to sandy till.
Grey till	Grey to dark grey, bentonitic till.

Unconformity.

Upper Cretaceous.

Member	Thickness in Feet	Lithology
Oldman	0' to 100'	Continental, brownish grey sand and calcareous shale and silt.
Upper Birch Lake	55'	Continental and marine, grey to yellow, medium grained sand.
Mulga	40'	Marine, grey shale with silt lenses and carbonaceous material.
Lower Birch Lake	120'	Continental and marine, massive crossbedded sandstone, buff-coloured, containing lenses of harder sandstone.
Grizzly Bear	40'	Marine, dark grey-blue shale, containing iron and sandstone nodules.

Member	Thickness in Feet.	Lithology
Upper Ribstone Creek	40'	Continental and marine, greenish yellow, massive, soft sandstone at top; green carbonaceous shale, coal and light grey sandstone at base.
Vanesti	80'	Marine, grey shale, silty shale, clayey shale, and fine sand.
Lower Ribstone Creek	90'	Continental and marine, massive, yellow sandstone; fine grained grey sandstone; grey silty shales; thin coal seams.
Shandro	70'	Marine, dark grey shale with calcareous and arrenaceous concretions; carbonaceous shale; brownish-grey silty shale.
Brosseau	95'	Continental and marine, fine, grey calcerous sandstone; sandy, brownish grey shale.
Lea Park	560'	Marine, grey, silty shales with local intercalations of sandy shale, ironstone concretionary bends, and bentonite.
Colorado Group		This group is not exposed in the map area, but underlies the above mentioned formations.

The thicknesses and descriptions of bedrock are given according to the Imperial Kinsella well No. 4, after E. W. Shaw and S. R. I. Harding (1949).

DESCRIPTION OF GLACIAL TILLS.

Three different tills were found in the area. The oldest till is the Grey till which occurs sporadically in the region. The Viking till forms the surface cover over most of the area west of the Coteau ice advance boundary. Only one roadcut was found which shows the Grey till and the overlying Viking till undisturbed in one section (Tp.55, R. 12-west of the fourth, S. 3, 200 feet west of the SE corner).

The Coteau till is the youngest of the three tills and covers

the country east of the terminal Coteau ice advance boundary (fig. 2).

The Grey Till.

The Grey till is from light to dark grey in colour, tough, bentonitic, and contains coal fragments picked up from the underlying bedrock. Sometimes the Grey till grades from a bentonitic to a sandy variety without any apparent change in colour. The Grey till found in eastern part of the province is a little lighter in colour than the Grey till found in the Big Bend section on the North Saskatchewan River west of Edmonton. No weathering or leaching of carbonates was observed on the tops of the Grey till in the region studied. A few sections on the North Saskatchewan River banks in the eastern part of the province show the Grey till, but unfortunately all the examined sections were obscured by slumping and no definite conclusions could be reached from them.

The Viking Till.

The Viking till is brown to dark brown in colour, loosely consolidated, and medium sandy in texture. This till can be described as being composed of approximately equal amounts of sand, silt, clay, and smaller amounts of gravel. In handspecimen the Viking till compares favourable to the Brown till of the Edmonton region. It is the author's opinion that in this report the term Viking till should be used in preference to the term Brown till because no conclusive evidence has been given that these tills were deposited by the same glaciation. Further the Edmonton region is separated

from the Viking moraine by the Buffalo Lake moraine and at the present time it is not known if the Buffalo Lake moraine represents a terminal or a recessional moraine.

The Coteau Till.

The Coteau till is light brown to brown in colour, sandy in texture, and loosely consolidated. Generally, the Coteau till is more sandy in handspecimen than the Viking till and contains limestone pebbles in the unleached portions of the soil profiles. There is a striking difference between the Coteau and the Viking tills at the Coteau ice advance boundary. East of the Coteau border the Coteau till becomes darker in colour and looks more like the Brown or the Viking till. In the Coteau moraine itself the character of the Coteau till varies over small distances. Some hills have sandy light brown to yellow till on the summits and brown to dark brown clayey till at the base. At a few places the two varieties of Coteau tills have been observed in a single roadcut. Such a roadcut is shown on Plate 9 A. Here the dark brown till is overlain by the light brown variety. It is probable that the light brown surface till represents superglacial or ablation till. The texture of the till in the area between the Coteau moraine and the Coteau ice advance boundary is sandy and in some places the whole countryside is covered with sand.

Recent Deposits.

The recent deposits of the area are comprised of windblown sand and loess which accumulated in some depressions. Muck and bottom land deposits of the area are also classified

as recent. Generally, the recent deposits are local in character and do not form any extensive accumulations.

Leaching of Carbonates.

Field observations did not reveal any break in the depth of leaching of carbonates in the soil profiles developed on the Viking and the Coteau tills. The average depth of leaching was found to be 23 inches. Some deviations of this value were noted which were probably due to the difference in the texture of the tills. It was noted that sandy phases had a deeper depth of leaching as compared to clayey phases of the same till.

PLEISTOCENE HISTORY OF THE AREA

There were at least three major glaciations in the area studied. These glaciations are represented by the Grey till, the Viking till, and the Coteau till. It is difficult to correlate these glaciations with other regions in North America or even in Alberta because there has been no mapping done in the adjacent areas. Probably the Viking till which covers much of the area mapped is of the same age as the Brown till found at the surface in other places in Alberta. However, until further mapping in the province shows that the Viking till is correlative with the Brown till the author prefers to use the term Viking till to denote the surface till in that area west of the Coteau boundary and east of the Buffalo Lake moraine.

The Grey Till Stage.

In many areas of Alberta sections of glacial deposits show a basal Grey till which rests on bedrock or Saskatchewan Sands and Gravels. Although it is not known whether or not this till was deposited by the same glaciation all the evidence to date would suggest that it was. Over much of the region studied the Grey till has been removed by subsequent glacial erosion and only a few patches are left in the east central part of the province.

No interglacial or interstadial deposits were found separating the Grey and the Viking tills. Further no evidence of soil formation or leaching was found at the top of the Grey till. It is difficult to determine the correlation of the Grey till from the above facts and in the author's opinion

more work has to be done on the problem before any conclusions can be drawn.

The Viking Stage.

The next glaciation in the area was the Viking glaciation. The Viking ice overrode the entire area and deposited the surface covering till west of the Coteau ice advance boundary. The Viking glacier removed the pre-existing Grey till cover and only left small isolated patches of this till in some depressions. In the Vermilion area the Viking glacier must have been undersaturated with debris because it left a thin till cover, 4 to 7 feet in thickness, over the bedrock. Another very significant feature of this glaciation is that it contorted the underlying soft bedrock.

After depositing the Viking moraine this glacier retreated to the east beyond the Coteau boundary. The duration of the interval separating the retreat of the Viking ice and the oncoming Coteau advance is uncertain because there have been no exposures found of the Viking and the Coteau tills in one section. In the author's opinion it is reasonable to assume that the Viking-Coteau interval was short. This can be supported by the fact that the area glaciated by the Viking glacier has retained such youthful features as well preserved kettle holes, undrained lakes, steep sided hills, and many other characteristics of youthful glacial topography.

The Coteau Stage.

After the retreat of the Viking ice the Coteau glacier

advanced up to the position outlined on fig. 2. At this point the climate changed and the front of the glacier became stagnant. In the area of Lloydminster ice block ridges were produced between large stagnant ice blocks (plate 1 and 7). At the edge of the glacier in that area some ice blocks were buried in glacial debris and after melting they produced kettle holes. Farther to the north the ice retreated by backwasting. Short halts of the retreating glacier are marked by flat and broad ridges mentioned before. Two major halts produced deflections in the North Saskatchewan and Vermilion rivers.

After the Coteau ice has retreated from 10 to 20 miles behind the outer advance limit it stayed long enough in one location to deposit the Coteau moraine. At this time the North Saskatchewan River flowed along the front of the glacier and retained this same direction after the ice disappeared. The final stage of the Pleistocene history of the area was the retreat of the Coteau glacier.

Most writers agree that the age of Coteau maximum is Wisconsin. Horberg (1952), Johnson and Wickenden (1931), Bretz (1943) and Alden (1932) classified the Coteau glaciation as late Wisconsin.

Horberg (1952) mentions the Coteau moraine in his article on the Lethbridge region and assumes it to be Mankato in age. Johnson and Wickenden (1931) believe that the Coteau moraine marks the limit of a late Wisconsin ice advance. Bretz (1943) writes; "The Altamont (Coteau) moraine is accepted in the present study as terminal late Wisconsin

equivalent to the Des Moines, Mankato and Port Huron moraines." Alden (1932) believes that the Coteau moraine is late Wisconsin and represents the last ice advance of the Keewatin glacier in western America. The writer agrees that the Coteau glaciation is the last one in the area studied but does not commit himself to a definite age because in his opinion there has not been enough work done in North and South Dakotas, and Minnesota in order to correlate this or any other Albertan glaciation with the Eastern American Pleistocene stratigraphy.

LABORATORY INVESTIGATIONS.

The laboratory investigations included mechanical and mineralogical analyses of soil samples taken from the surface covering tills of the area studied. The results of the mechanical analyses were plotted on cumulative curves. The heavy minerals were separated and counted and the percentages of the different mineral species determined.

Sampling.

The samples for the laboratory analyses were collected from representative areas from each of the main glaciated regions. At each locality a hole was dug and samples were taken every 6 inches from the surface down to the line between the "A" and "B" soil horizons. Then one sample was taken from the boundary separating the "A" and "B" soil horizons, one from the "B", and one from the "C" soil horizon. Tills having similar texture were used in this study.

The first digit of the sample number signifies the location of the sample. The second part of the sample number, which is separated from the first by a hyphen is related to the depth at which the sample was taken; eg. sample 6-2 would indicate the location of the sample by the number 6 (see appendix A) and 2 the depth (1 foot) from the surface at which the sample was taken (see appendix A).

Outline of the Mechanical Analyses Procedure.

The following flowsheet shows the main steps involved in the mechanical analyses procedure.

1) 150 grams of the sample was removed and dried.
2) Material above 2 mm size was removed by wet sieving.
3) Material above 0.062 mm was separated from the finer portion by wet sieving.
4) The fraction between 2 mm and 0.062 mm was sieved using the following screens:

18 mesh	- 1.00 mm
35 mesh	- 0.50 mm
60 mesh	- 0.25 mm
80 mesh	- 0.177 mm
120 mesh	- 0.125 mm
170 mesh	- 0.088 mm
230 mesh	- 0.062 mm

5) Each sand fraction separated in step 4 was weighed and the material below 0.062 mm was added to the minus 0.062 mm portion of the sample.
6) The material below 0.062 mm from step 3 plus material from step 5 wad dried at 120 C and its weight determined.
7) Finally, 10 gr of the material from step 6 was taken and sedimentation analysis was carried out on it (pipette method) as outlined by J. A. Toogood and T. W. Peters (1953).

During the course of performing the mechanical analyses it was found that ordinary washing procedures did not remove all the silt and clay from the sand fraction. However, the author found that prolonged boiling in distilled water favoured a better separation. Best results were obtained

by boiling the sample three times in about 750 to 1000 cc of water for about 60 minutes each time. The main difficulty in using the boiling procedure is that when the clays are oven dried it is not always possible to fully re-disperse them.

Results of Mechanical Analyses.

The results of mechanical analyses were plotted on cumulative curves (Appendix B). The silt-clay break was taken at 2 microns and no size analyses were made on material below this size. The upper limit was set by the 2 mm size or the gravel and sand break. All samples of one profile were plotted on a single graph in order to make correlations easier. The shapes of the cumulative curves show that sand, silt, and clay fractions are represented on the average in approximately equal amounts in all of the samples. The different profiles have different amounts of sand, silt, and clay but this ratio between them is usually similar for all of the analyzed samples of a single profile. It is interesting to note that there is no major accumulation of clay within the soil profile. It is generally considered by soil scientists that clay and other colloids migrate downward from the "A" soil horizon and accumulate in the "B" horizon. This lack of secondary accumulation of clay in the soils studied might be explained by the small amount of downward percolating water in the region under study, and also that the soils did not have sufficient time to develop this characteristic.

Outline of the Heavy Mineral Analysis.

The portion of sand between the 100 and 200 mesh size was separated, weighed, and placed in tetrabromoethane (sp. 2.965) and the heavy minerals were separated. The heavy minerals were mounted in aroclor (n 1.66) and examined under the microscope. An average of 350 to 400 grains were counted from each slide and the percentage of the individual minerals calculated (Appendix A). The heavy minerals were weighed and the percentage of heavy minerals in the 100-200 sand fraction calculated.

The general procedure was satisfactory and good results were obtained. The separations did not involve any major difficulties. The only drawback was in the actual mounting of the heavy minerals. It was noted that certain of the heavy minerals concentrated in one patch of the fraction and it was difficult to get a homogeneous mixture of a small fraction of the heavy minerals for mounting purposes. This was overcome, however, to a large degree by mixing the whole heavy mineral fraction prior to mounting.

Description of the Heavy Minerals.

Hornblende (plate 3 A)

The hornblende is fresh in appearance and shows no evidence of weathering in the examined samples. It is predominantly green to bluish-green although some of the varieties are pleochroic from brown to green. Brown hornblende with an index higher than 1.66 was classified as basaltic horblende. The green to bluish-green hornblende

is considered to be of metamorphic origin. Black hornblende listed in the tables is a variety of the green hornblende but probably very rich in iron and consequently almost opaque in transmitted light. The majority of the hornblende examined show well defined cleavage outlines on the fragments. There is no evidence of weathering found on the hornblende throughout the individual soil profiles. Hornblende is the most abundant heavy mineral in all suites except for the suite number 6, where it makes up only 20 percent of the total heavy minerals counted.

Tremolite (plate 3 B)

The colourless varieties of amphiboles were counted as tremolite. Small amounts of this mineral are present in all the samples.

Pyroxenes.

The pyroxenes are broken down into monoclinic and orthorhombic types. Most of the grains show no evidence of weathering.

Monoclinic Pyroxenes. (plate 3 C and D)

The monoclinic pyroxenes usually predominate over the orthorhombic varieties. The monoclinic pyroxenes counted in the slides are for the most part colourless except for augite which shows green nonpleochroic colouration. Monoclinic pyroxenes average about two to three percent of the suites.

Orthorhombic Pyroxenes (plate 3 E and F)

Hypersthene generally shows marked pleochroism from

bluish-green to red or to reddish-green. Enstantite occures as colourless grains.

Epidote (plate 4 E)

The majority of the epidotes has a distinct pleochroism from yellowish-green to white. Some of the altered epidotes show white in reflected light. This alteration probably took place prior to deposition. The number of altered grains is approximately the same in all of the examined samples. Most of the examined grains are irregular to subangular in outline.

Zoisite

Only traces of zoisite were noted in 18 out of the 30 examined samples. Most of the grains are colourless to grey in colour and fresh in appearance.

Garnet (plate 4 A)

Although most of the garnet is colourless, pink, red, yellow, and brown varieties are found. A typical grain may be described as being a fracture fragment showing well pronounced conchoidal fracture. All the grains are angular and no rounding on any grains was observed. The garnet shows no evidence of weathering. This mineral averages 10 to 15 percent of the heavy mineral suite.

Magnetite

Magnetite and hematite are grouped together. The percentage of magnetite was found to be approximately the same

in all of the analysed samples. It varied in amount from 10 to 15 percent of the heavy minerals.

Limonite.

All opaque minerals having an earthy appearance and yellow to brown colour in reflected light are considered as limonite. The amount of limonite is about the same in the individual soil profiles, but varies in different locations. Profile number 6 has the highest value of 23 to 28 percent. All the other profiles analysed have a much lower percentage of limonite, usually from 5 to 15 percent.

Apatite (plate 5 C and D)

Apatite occurs both as rounded and fractured grains. Some grains showing crystal outline were also observed. All the apatite noted was colourless. In the upper parts of the soil profiles this mineral shows a browhish colouration and uneven surface which may represent incipient weathering. The percentage of this mineral varies from 1 to 5 percent in the examined samples and shows some increase with depth in a few profiles.

Tourmaline (plate 5 B and E)

Brown, green, pink, bluish-grey, and brownish black tourmaline grains are present in the samples. Some of the tourmaline shows rounded secondary overgrowths of a colourless variety of the mineral. The amount of tourmaline is never high and varies from traces to the highest value of 1.6 percent. Abount one half of the tourmaline grains have

good crystal outline.

Zircon (plate 4 C)

Zircon was found in all of the samples. The colourless variety is predominant and the yellow zircon was rare. Generally the grains show good crystal outline but quite a few rounded grains were observed. It was noted that the larger zircon grains showed better crystal outline.

Titanite (plate 4 B)

Titanite observed in the samples is generally colourless or yellow. The colourless grains have on the average a better crystal outline than the yellow varieties. The mineral occurs as traces in most of the slides and seldom attains a value higher than one percent.

Rutile (plate 4 D)

The colour of the rutile grains varies from deep reddish-brown to deep red. Only traces of this mineral were noted in the slides.

Topaz.

Only traces of topaz are present in some of the samples. The grains of this mineral are colourless.

Staurolite.

Very few grains of staurolite were observed in the samples. For the most part the mineral is golden-yellow in colour and has a very angular outline.

Andalusite

Andalusite occurs as irregular to subhedral grains some of which have carbonaceous inclusions. The amount is usually small but sometimes attains a value higher than one percent. No marked alterations were observed on this mineral.

Monazite.

Monazite is usually yellowish in colour and does not show crystal outline. It is present only in traces.

Sillimanite.

Only traces of this mineral were noted in about one half of the examined slides. Most of the grains are quite clear and fresh.

Chlorite.

Some green to grey chlorite grains were observed in a few of the samples. The grains show aggregate polarization in the majority of the fragments and only very few grains are single crystals. This mineral occurs only as traces in some of the samples and is absent in others.

Chloritoid.

Chloritoid and serpentine are classified together. Only 8 samples have traces of this mineral group. The grains are green in colour, irregular in outline, and show aggregate polarization.

Leucoxene.

Very few leucoxene grains were observed. They are usually irregular in outline and distinctly white in

reflected light. It is possible that a few grains of this mineral might have been confused with limonite.

Anhydrite.

A few colourless and brownish grains of anhydrite were observed in traces in a few slides.

Biotite.

Brown, brownish-red, and green biotite flakes occur in small amounts in just about all of the samples.

Gold.

Gold flakes were found in five of the thirty heavy mineral suites examined. Sample 5-4 shows three grains of gold in the heavy mineral count and 12 grains in the whole slide. The gold flakes are irregular in outline and comparatively thin.

Kyanite. (plate 3 F)

Only 5 samples show traces of kyanite. This mineral usually has good cleavage outline and is colourless.

Pyrite.

Profile number 6 contains a few grains of an opaque mineral which has a metallic lustre and is light yellow in colour. Tentatively this mineral is considered to be pyrite,

Altered Minerals Translucent at the Edges. (Unindentified)

Altered minerals which have unaltered borders are classified under this heading and are further broken down into groups according to the colour in reflected light. The white coloured group is the largest as is evident from the tables

and averages from 1 to 4 percent.

Glaucophane.

Only two grains of glaucophane were observed in samples of profile 1 and profile 6.

Interpretation of the Heavy Mineral Analyses.

All the analysed samples show similar heavy mineral suites. The suites are composed of stable, metastable, and unstable minerals. The percentages of the different mineral in the individual samples studied are quite similar. No appreciable weathering of the metastable and the unstable minerals was noted in the examined soil profiles. The only exception was apatite which shows incipient weathering in the upper parts of the soil profiles. This weathering expressed itself in the light brown surface colouration of the grains and etching of their surfaces. Apatite grains from the "B" and "C" horizons were usually clear and had a smooth surface. Further the weathering of apatite is evident from the fact that it is present in smaller amounts in the upper portions of some of the profiles.

The fact that there is practically no weathering of the heavy minerals in the soil profiles analysed suggests that the Coteau and the Viking tills are quite young and that the time interval separating them is relatively short. However, it should be pointed out that a cold climate and a low precipitation such as is found in this region might not produce much break down of the silicates over a long period of time. Nevertheless, a shallow soil profile has

developed on the Coteau till since late Wisconsin (?) time. Consequently it is not unreasonable to suppose that if there had been a long time break between the deposition of the Viking and the Coteau tills that a deeper and better developed soil profile should now be found on the Viking till. As no distinct break in depth of soil profile, depth of leaching, or break-down of silicates was found in these two tills it is suggested they were deposited during the same major glacial stage. Thus if the Coteau moraine is taken as late Wisconsin (?) it is also possible that the Viking till is Wisconsin in age.

The heavy mineral analysis on the Athabaska sandstone done by J. C. Mawdsley in 1954, a student at the University of Alberta, revealed the presence of large number of tourmaline grains with secondary overgrowths (plate 5 A). Similar tourmaline grains with rounded overgrowth were observed by the author in some of the till samples (plate 3 B). It is believed that part of the tourmaline in the Viking till originally came from the Athabaska sandstone and the overgrowths were rounded during transport. This means that the ice was moving in a south-westerly direction over northern Saskatchewan and Alberta. This direction agrees with striae and drumlins found in the region of Cree Lake, Saskatchewan, by J. C. Sproule (1939).

ECONOMIC GEOLOGY

Sand and Gravel.

The western border of the Coteau ice advance is marked by outwash deposits of sand and gravel. Field observations revealed that the best gravel pits are located right at the Coteau advance border. At the present time the existing supplies do not satisfy the demand of the area not only in general constructions but also in road constructions. It is suggested that some prospecting could reveal new gravel and sand deposits of economic value along the Coteau ice advance border.

Water Supply.

Generally, the terminal Coteau ice advance region is lacking in good water supplies. It was noted in the field that most of the drilling for water is done in the Lea Park formation, which is a dense bentonitic clay deposit and does not contain any water at all. Some of the producing wells of this area which are located in thick glacial till sections yield satisfactory amounts of water. Further it was observed that most of the drilling is being done in depressions where the till cover is quite shallow and the bedrock close to the surface. Such wells usually end up in the Lea Park formation and are consequently dry. It is suggested that if wells could be drilled on hill tops where there are thick glacial deposits more producing wells could be gained.

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APPENDIX "A"

Distribution of Sample Profiles.

The sample profiles were collected from the following areas:

a) Profile one was taken from the Coteau terminal ice advance region.

b) Profile three was collected from the Coteau moraine itself.

c) Profile four was taken a few miles west of the Coteau ice advance boundary in the Vermilion area.

d) Profile five came west of Vermilion.

e) Profile six was taken west of the Viking moraine and east of the Buffalo Lake moraine.

The distribution of the samples is shown on fig. 3.

Location of the Sample Profiles.

Profile one : Tp. 52, R. 3 -W. of 4th, Sec. 31 , N.W. corner, 800 feet south .

Profile three: Tp. 53, R. 3 -W. of 4th, Sec. 36, N.E. corner, 0.1 miles west.

Profile four: Tp. 53, R. 5 -W. of 4th, Sec. 8, N.W. corner.

Profile five: Tp. 50, R. 7 -W. of 4th, Sec. 25, N.W. corner.

Profile six : Tp. 53, R. 17 - W. of 4th, Sec. 9, S.E. quarter, N.E. corner.

Depths of Leaching of Carbonates at the Sample Profile Locations.

Profile 1: from 21 to 23 inches

Profile 3: from 25.5 to 26.5 inches

Profile 4: from 23.5 to 24.5 inches

Profile 5: from 23.5 to 24.5 inches

Profile 6: from 24 to 25 inches

Position of the Samples in the Profiles (in inches from the Surface).

	Sample					
Profile	1	2	3	4	5	6
1:	6"-7"	12"-13"	18"-19"	21.5"-22.5"	28"-29"	44"-45"
3:	6"-7"	12"-13"	18"-19"	25"-26"	31"-32"	47"-50"
4:	6"-7"	12"-13"	18"-19"	23.5"-24.5"	29"-30"	49"-54"
5:	6"-7"	12"-13"	18"-19"	23.5"-24.5"	29"-30"	50"-54"
6:	6"-7"	12"-13"	18"-19"	24"-25"	30"-31"	54"-58"

Samples 1, 2, and 3 were taken from the "A" soil horizon. All number 4 samples come from the boundary between the "A" and the "B" soil zones. All number 5 samples are from the "B" horizon and all number 6 samples represent the "C" horizon.

Percentages of the Heavy Mineral Fractions as Compared to the 100 to 200 mesh Sand Fractions.

Sample	Profile 1	3	4	5	6
1:	1.35	2.62	1.81	1.83	0.96
2:	1.64	3.14	1.35	2.05	1.08
3:	1.54	2.37	1.68	2.10	1.03
4:	1.55	2.44	1.87	2.12	0.99
5:	1.44	2.62	1.92	1.95	0.88
6:	1.53	2.44	1.58	1.95	1.12

TABLE 1

Heavy Mineral Count of Profile 1.

(All values are given in percentages. T - denotes trace)

Mineral	Sample 1-1	1-2	1-3	1-4	1-5	1-6
Hornblende met.	48.9	42.6	42.8	33.6	35.8	34.5
basal.	0.8	1.1	1.5	T	T	0.7
black	T	0.8	0.8	1.0	0.8	0.7
altered	1.7	1.9	1.3	2.0	T	1.5
Tremolite	0.8	T		T		1.5
Garnet white	8.7	9.0	10.2	8.8	14.3	11.5
pink	T	T		1.0		1.0
red	T			T		
brown	T			T		T
Hypersthene	1.4	1.9	1.8	4.9		T
Enstantite	1.1		T		T	T
Pyrox. Mon.	1.4	1.1	2.1	2.1	1.7	0.7
Augite	1.1	T		1.0	1.1	
Magnetite	8.7	11.5	10.2	14.9	15.7	13.2
Limonite	11.2	11.8	10.5	8.6	7.8	15.7
Epidote	2.5	3.3	2.8	3.9	5.0	4.0
Zoisite	0.8		0.8	T	0.7	T
Apatite	2.2	2.5	2.1	3.9	5.0	3.2
Staurolite		T	T	T	T	T
Andalusite	T	1.4	1.3	T	T	T
Rutile	T	T	T	0.8	T	0.7
Titanite	1.1	0.8	0.8	0.8	T	T
Monazite		1.1		T	T	
Kyanite		T				
Biotite		0.8		T	1.1	T
Leucoxene		T		1.8	1.0	
Tourmaline	T	T	T	T	1.7	0.7
Chlorite		T				T
Zircon	T	T	T	1.0	2.2	1.7
Chloritoid	T		T	T		
Sillimanite	T		T	T	T	T
Topaz				T	T	T
Gold					T	T
Glaucophane	T					T
Anhydrite						T
Altered to white	2.6	4.1	4.1	4.6	2.5	2.2
brown		T	1.0			
black				T		T
Unindentified	T	T	1.0	T	T	T
Isotropic (n < 1.66)	T			T		T

TABLE 2

Heavy Mineral Count of Profile 3.

(All values are given in percentages. T - denotes trace)

Mineral		Sample 3-1	3-2	3-3	3-4	3-5	3-6
Hornblende	met.	41.6	47.2	49.6	44.4	38.7	40.2
	basal.	T	T		0.8	2.0	1.3
	black	1.7	0.8	0.8	T	T	0.8
	altered	0.8	1.1	1.1	1.3	1.5	0.8
Tremolite		1.4	0.8	1.9	1.0	1.8	T
Garnet	white	15.6	17.9	16.6	12.6	14.7	14.6
	pink	1.1	1.4	0.8	T	T	T
	red	1.4	T		T		
	brown	1.1			T	T	0.8
Hypersthene		1.7	1.7	1.9	1.1	3.8	2.6
Enstantite		T		T	1.0	T	T
Pyrox. Mon.		1.4	1.4	1.1	2.6	1.7	2.9
Augite		1.1	T	1.3	1.3	1.5	T
Biotite						T	T
Magnetite		16.7	9.6	10.2	11.3	11.4	15.4
Limonite		3.6	4.5	3.3	5.5	7.0	5.3
Apatite		1.9	2.5	3.0	4.5	4.0	4.8
Epidote		0.8	1.7	1.1	1.3	1.7	2.6
Zoisite			T			T	
Gold							T
Titanite		T	0.8	0.8		T	0.8
Rutile			0.8	T	T	0.8	
Zircon		T	T	1.1	T	T	1.3
Staurolite		T		T	0.8	T	T
Tourmaline			0.8	0.8	T	1.0	T
Andalusite		T	1.1	T	T	T	T
Monazite		1.1	T	T	T	T	
Chloritoid		T	T				
Chlorite		T					
Kyanite			T	T			
Topaz				T		T	T
Sillimanite					T		
Anhydrite					T		
Isotropic (n < 1.66)				T	T		
Altered to	white	2.5	1.7	2.5	3.4	3.4	1.6
	brown		T	T			
	black					0.8	
Unindentified		T	T	1.3	T	T	T

TABLE 3

Heavy Mineral Count of Profile 4.

(All values are given in percentages. T - denotes trace)

Mineral	Sample 4-1	4-2	4-3	4-4	4-5	4-6
Hornblende met.	30.1	29.5	37.1	33.9	39.5	34.6
basal.	0.7	1.0	1.8	1.7	T	1.1
black	2.5	1.3	0.8	3.4	1.3	T
altered	1.9	T	T	T	T	T
Tremolite	2.2	1.2	2.0	2.2	1.1	1.1
Garnet white	13.9	28.3	11.0	11.5	15.2	11.4
pink	T	0.7	1.3	T	0.8	0.8
red		1.2		T	T	T
brown	-	T			T	
Magnetite	10.9	11.5	14.3	13.0	15.9	16.0
Limonite	10.7	7.1	7.7	10.8	4.3	11.1
Apatite	2.9	2.7	3.1	2.6	2.9	2.7
Epidote	3.7	3.9	5.9	2.9	2.4	3.5
Zoisite	T		T	T	T	
Pyrox. Mon.	1.0	T	0.8	1.4	0.8	1.9
Augite	1.0	T	1.3	T	2.2	T
Hypersthene	1.0	1.5	1.0	2.2	2.4	1.9
Enstantite	1.5	T	1.0	1.0	T	1.8
Tourmaline	0.7	T	1.0	0.7	1.3	1.3
Topaz	T		0.8		0.8	
Zircon	1.2	1.2	0.8	0.7	T	T
Titanite	T	T	T	0.7	T	T
Rutile	T		0.8		T	T
Andalusite	1.2	T	T		0.8	0.8
Biotite	2.7	T		0.7	T	T
Leucoxene	0.7	T	1.0	0.7		
Chlorite	T	T	T	T		
Staurolite	T	T	T	0.7	T	T
Monazite		T	T			T
Sillimanite		T	T		T	
Kyanite			T	T		
Anhydrite				T		
Chloritoid				T	T	
Isotropic ($n < 1.66$)						T
Altered to white	6.5	1.2	2.6	4.1	2.4	4.9
brown			T	T		
black		1.7	0.7	T		1.3
Unindentified	T	T	0.8	1.2	0.8	T

TABLE 4

Heavy Mineral Count of Profile 5.

(All values are given in percentages. T - denotes trace)

Mineral	5-1	5-2	5-3	5-4	5-5	5-6
Hornblende met.	37.9	43.1	45.1	40.7	41.4	48.6
basal.	T		T	1.2		1.0
black	2.0	T	T	0.7	T	0.8
altered	3.1	T	2.1	2.7	T	0.8
Tremolite	T	T	0.8		0.8	1.5
Garnet white	14.6	13.8	15.1	14.3	14.9	9.4
pink	1.0	T	1.0	T	T	1.0
red			0.8			
brown	T	0.8	T	T	T	
Magnetite	14.9	12.5	17.2	10.1	17.9	7.4
Limonite	8.4	8.7	4.0	6.4	4.4	9.7
Apatite	2.0	2.4	2.1	4.2	2.2	2.0
Epidote	1.8	2.4	1.9	2.9	2.5	2.8
Zoisite	T	T			T	
Pyrox. Mon.	1.8	2.2	1.6	2.0	1.7	3.3
Augite	0.8	1.9	T	T	1.4	0.8
Hypersthene	1.5	1.9	2.1	3.7	0.8	T
Enstantite		T	0.8		T	T
Zircon	0.8	T	T	1.0	2.2	T
Tourmaline	T	T	T	2.0	T	T
Titanite	T	1.1		T	0.8	1.0
Rutile			T			T
Topaz	T			T		T
Staurolite	T	T		T	T	T
Andalusite	T		T	0.7	T	0.7
Monazite	T	T	T	0.7		
Leucoxene			T			T
Anhydrite				T		T
Sillimanite		T		0.7	T	
Gold		T		0.7		
Isotropic (n < 1.66)				T	T	
Chlorite		T		T	T	
Biotite		0.8		0.8		1.8
Altered to white	3.8	1.9	2.1	1.7	2.2	2.0
brown						
black	T	T		T	T	0.8
Unindentified	T	T	T	T	T	1.0

TABLE 5

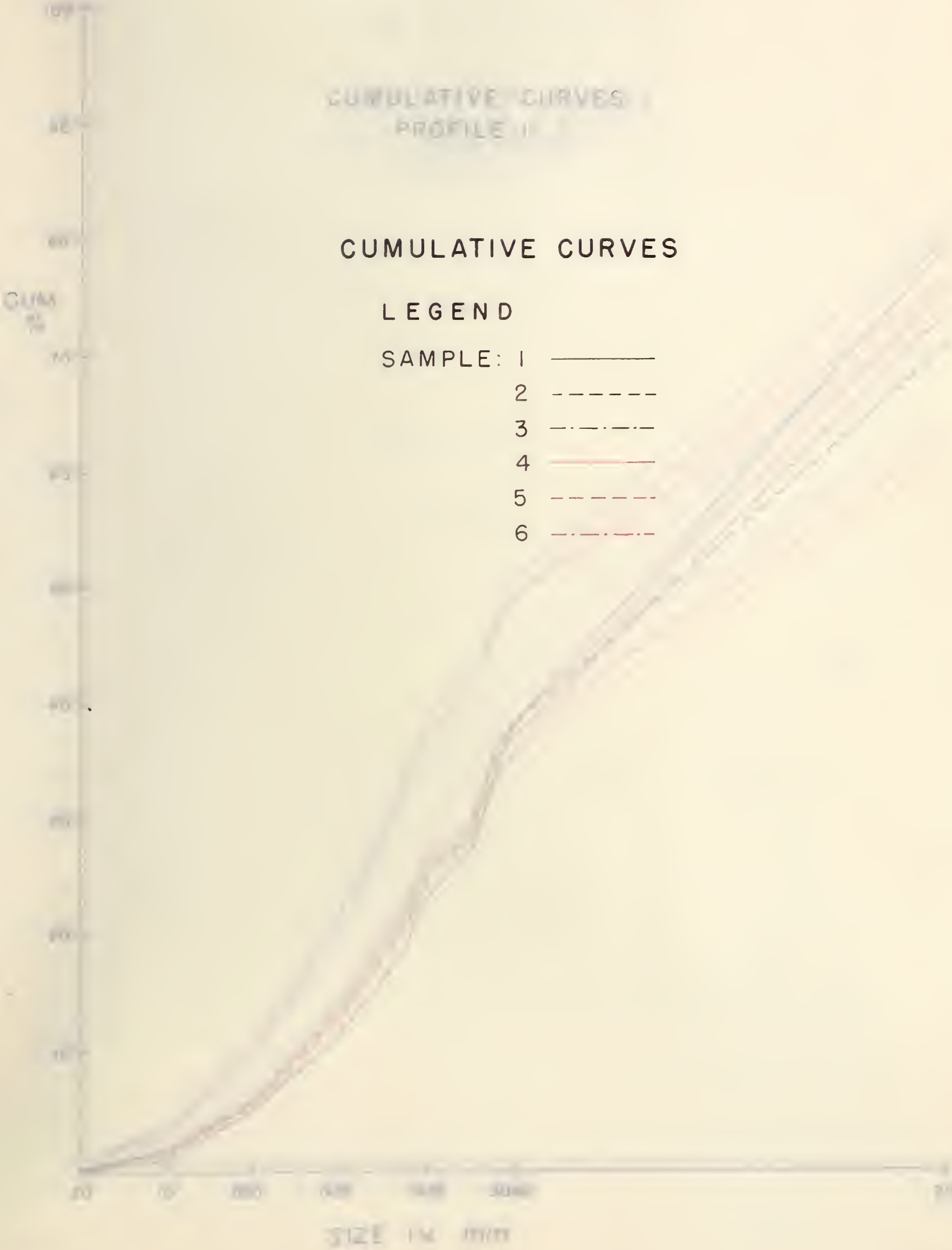
Heavy Mineral Count of Profile 6.

(All values are given in percentages. T - denotes trace)

Mineral	Sample 6-1	6-2	6-3	6-4	6-5	6-6
Hornblende met.	21.5	24.8	20.3	22.2	22.4	19.6
basal.	T		T	T	T	
black	T	T	T	0.8	T	0.8
altered	T	1.8	1.6	1.3	1.2	1.9
Tremolite	T	T	T	T	T	0.8
Garnet white	7.9	10.8	12.3	10.6	9.4	8.7
pink	T	T	1.4	T	T	T
red		T		T		
brown			T			T
Pyrox. Mon	2.2	1.0	1.6	1.5	1.2	1.6
Augite	T	T	T	T	1.2	T
Hypersthene	1.6	1.0	1.9	1.3	2.1	1.6
Enstantite	T	T	1.4	1.5	T	T
Magnetite	15.8	16.8	12.3	16.0	17.9	18.0
Limonite	28.0	23.7	24.7	22.7	23.8	24.9
Apatite	1.9	3.9	2.8	2.6	2.9	3.4
Epidote	4.6	3.6	3.3	2.8	3.2	4.5
Zoisite	T	T	T		T	T
Tourmaline	1.6	0.8	1.1	1.0	T	0.8
Titanite	1.9	T	0.8	0.8		0.8
Rutile		T	T	T	T	
Zircon	T	T		1.5	2.6	0.8
Staurolite	1.1		T		0.9	T
Andalusite	0.8			T	1.2	0.8
Monazite	0.8	T	0.8	1.0		T
Leucoxene			T	1.5	T	
Pyrite			T	T	0.9	
Biotite	T	T	1.1	T	0.9	1.6
Anhydrite		T	T			
Isotropic (n 1.66)			T	T	T	T
Glaucophane			T			
Kyanite			T			
Chloritoid				0.8		
Topaz		T		T		
Chlorite					T	
Sillimanite	T	T				T
Altered to white	3.5	4.9	5.8	5.7	3.2	3.4
brown	2.2	1.0				1.1
black						T
Unindentified	T	T	T	T	T	0.8

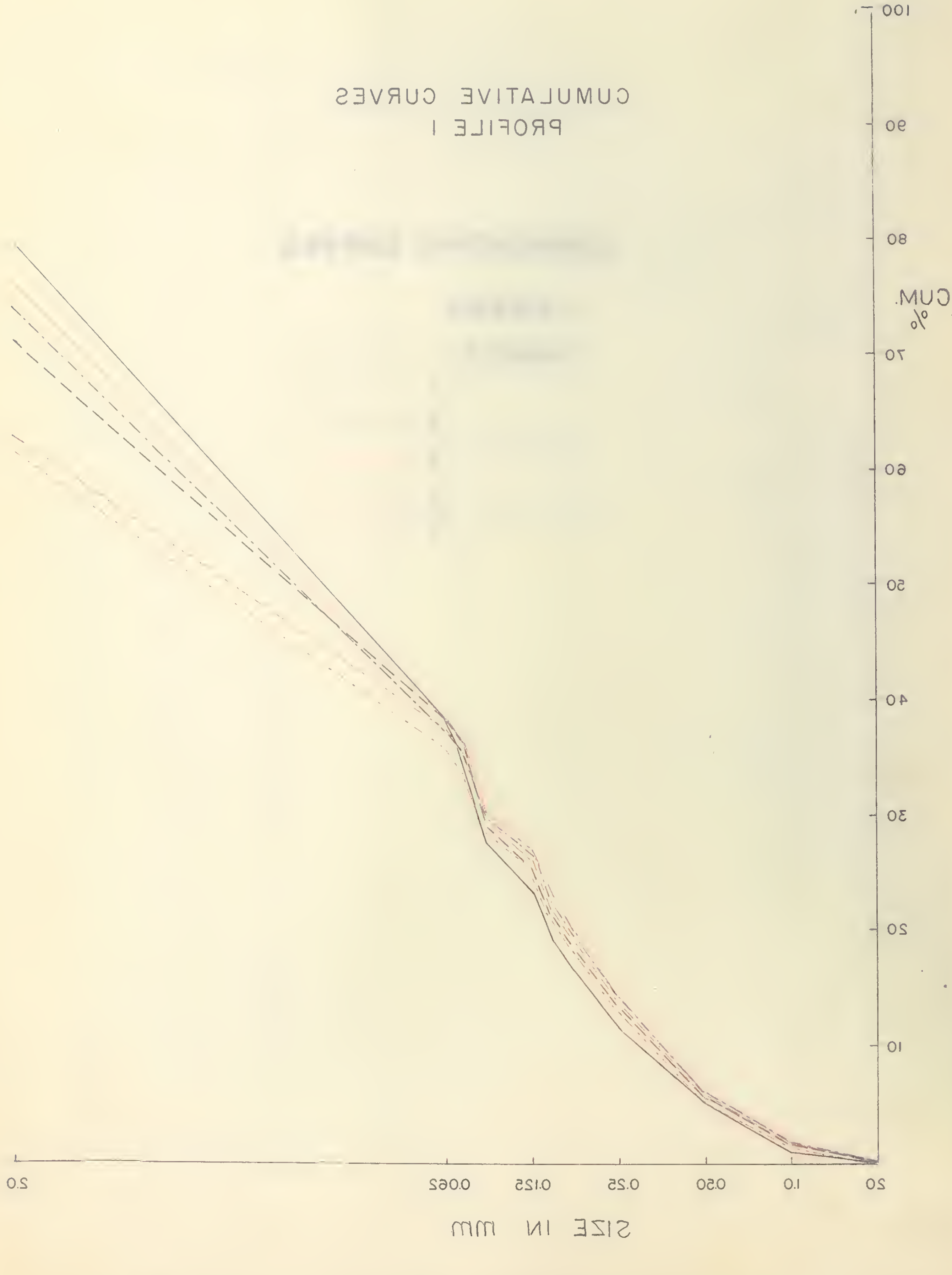
APPENDIX "B"

CUMULATIVE CURVES

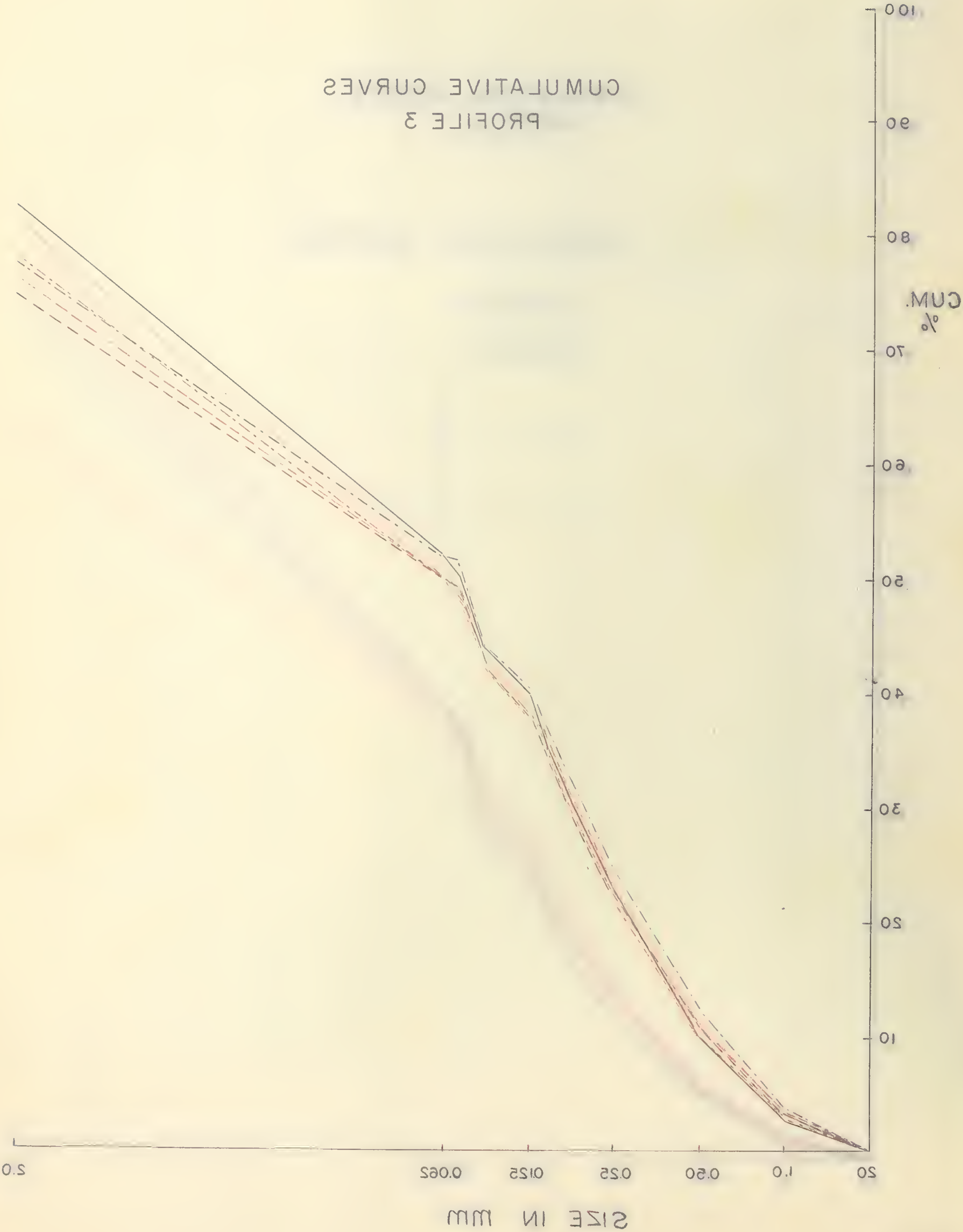

CUMULATIVE CURVES
LEGEND
SAMPLE: 1
2
3
4
5
6


CUMULATIVE CURVES
PROFILE I
CUM. %
100
90
80
70
60
50
40
30
20
10
2.0
1.0
0.50
0.25
0.125
0.062
2.0
SIZE IN mm

CUMULATIVE CURVES
PROFILE I




CUMULATIVE CURVES
PROFILE 3
CUM. %
100
90
80
70
60
50
40
30
20
10
20
1.0
0.50
0.25
0.125
0.062
2.0
SIZE IN mm


CUMULATIVE CURVES
PROFILE 3
CUM. %
100
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80
70
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10
20
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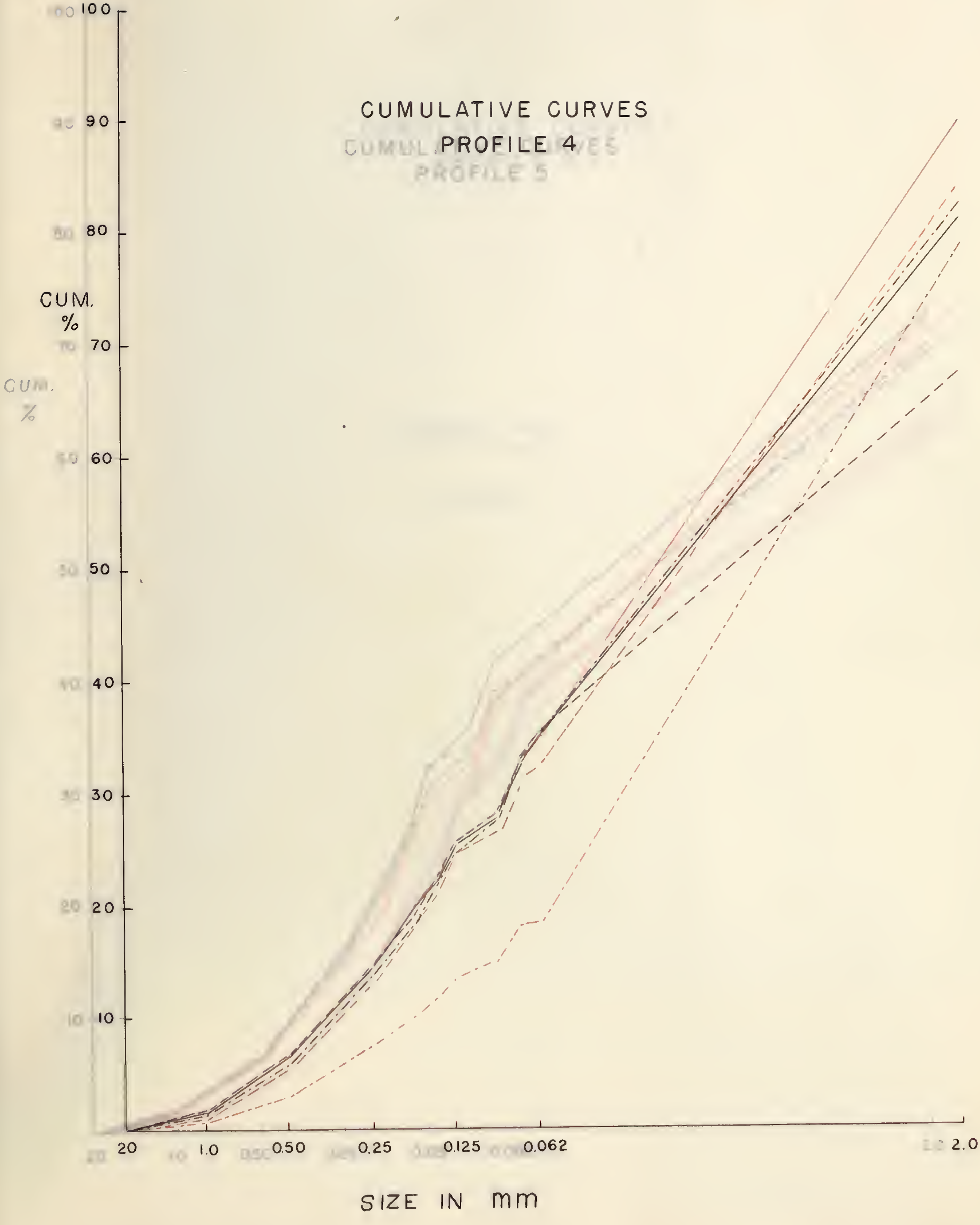
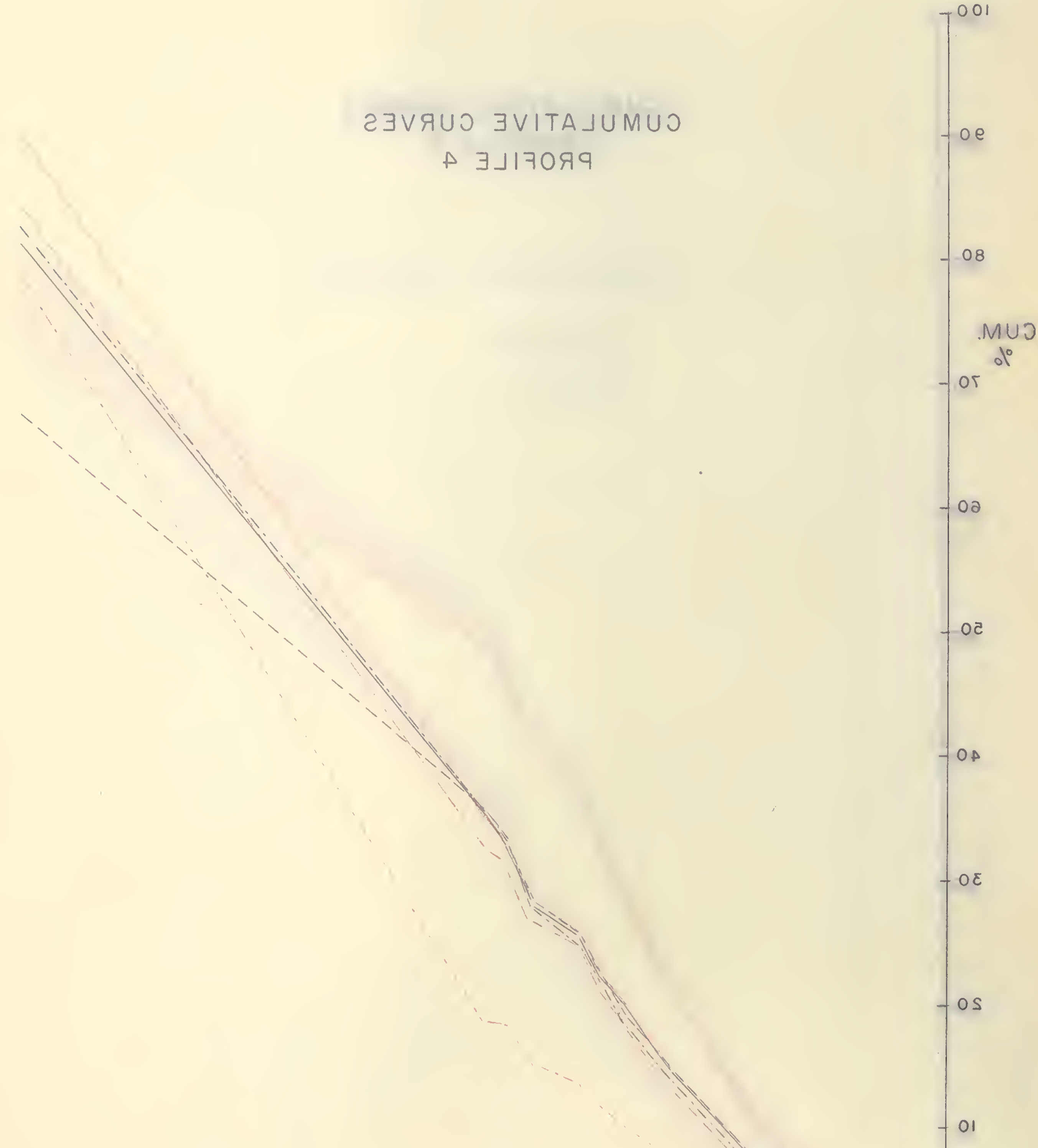
0.50
0.25
0.125
0.062
2.0
SIZE IN MM


CUMULATIVE CURVES
PROFILE 4
CUM.
%
100
90
80
70
60
50
40
30
20
10
20
1.0
0.50
0.25
0.125
0.062
2.0
SIZE IN mm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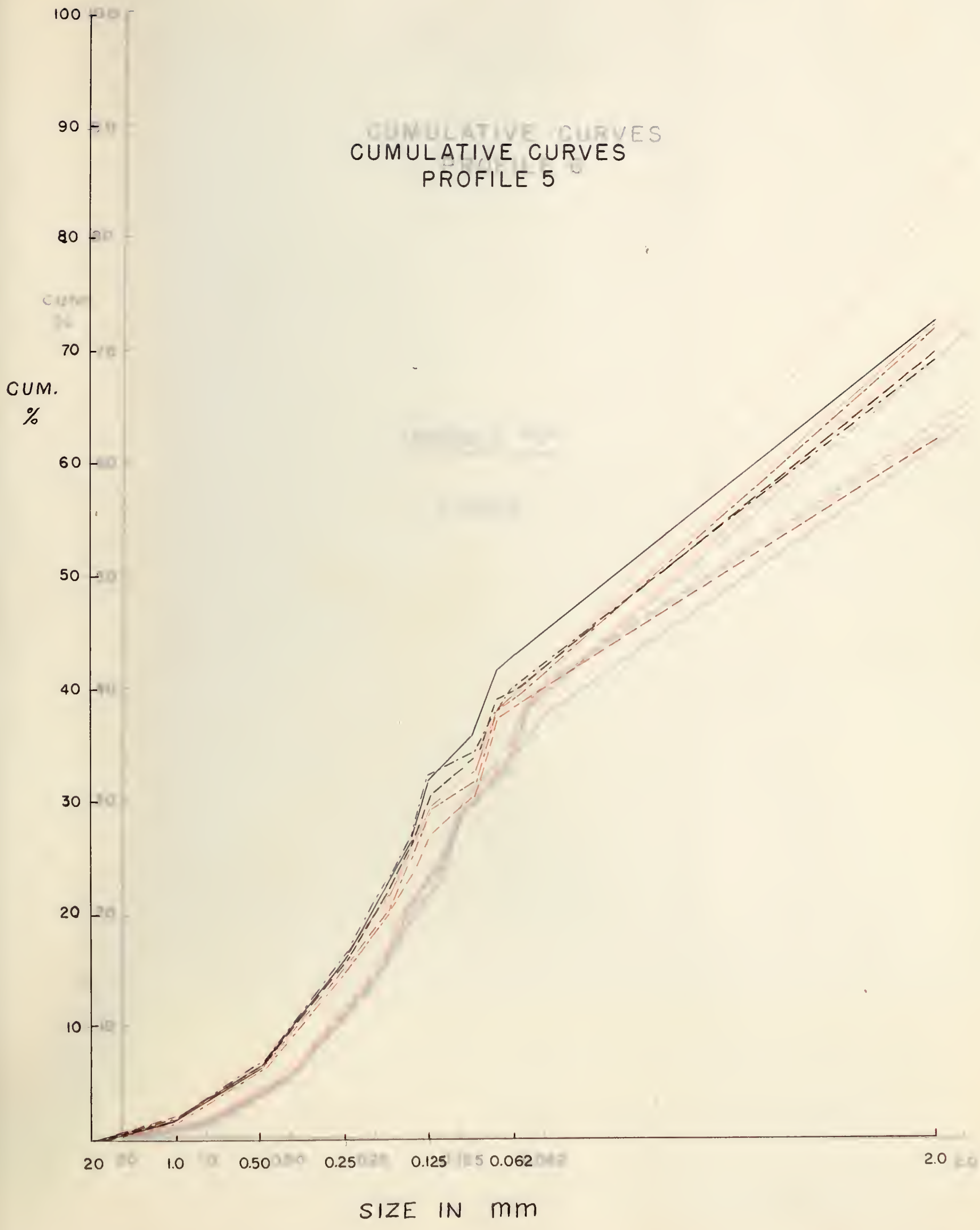
0.25
0.50
1.0
20
SIZE IN MM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PROFILE 5
CUM.
%
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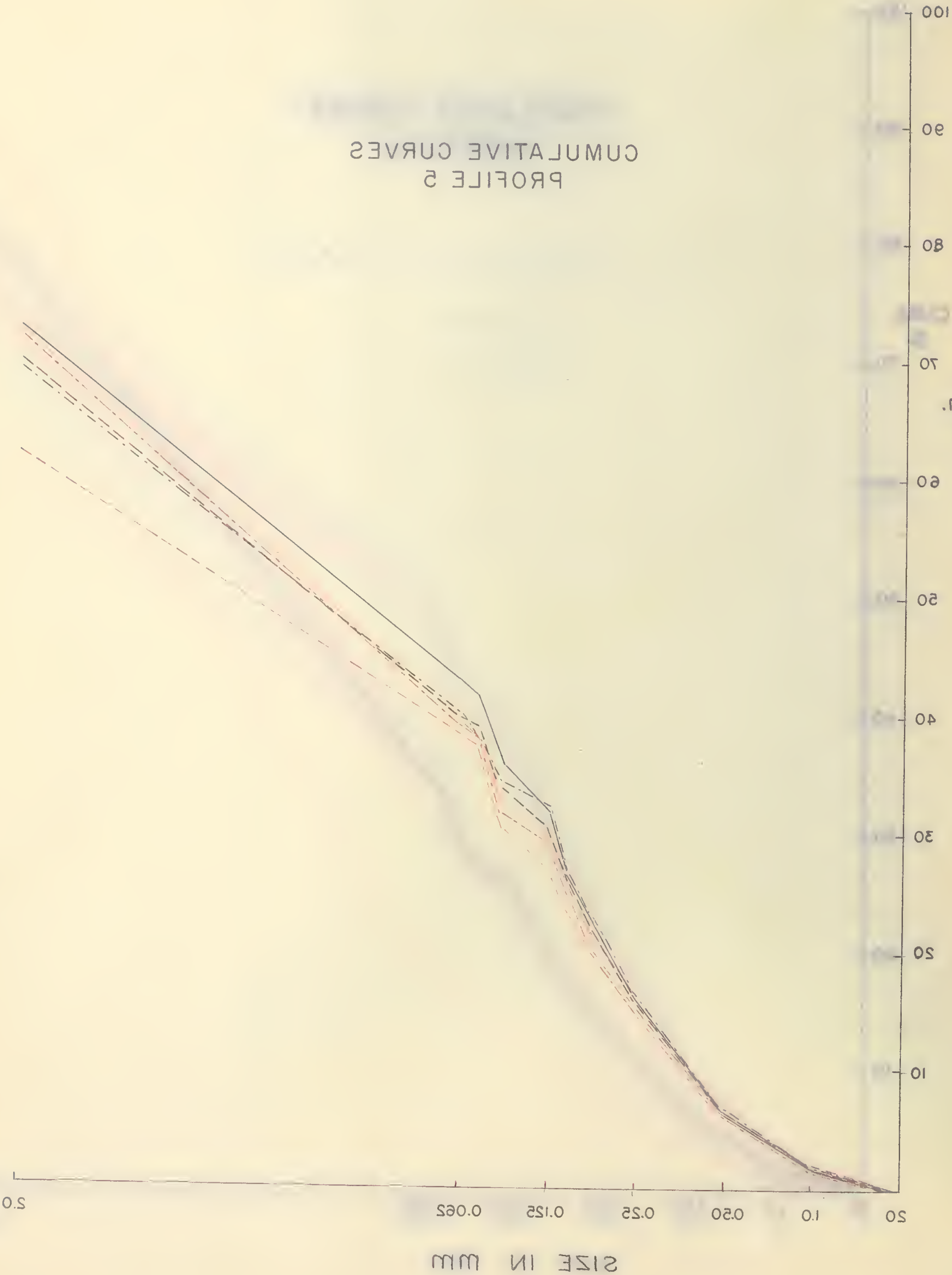
2.0
SIZE IN mm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PROFILE 5
CUM. %
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0.25
0.125
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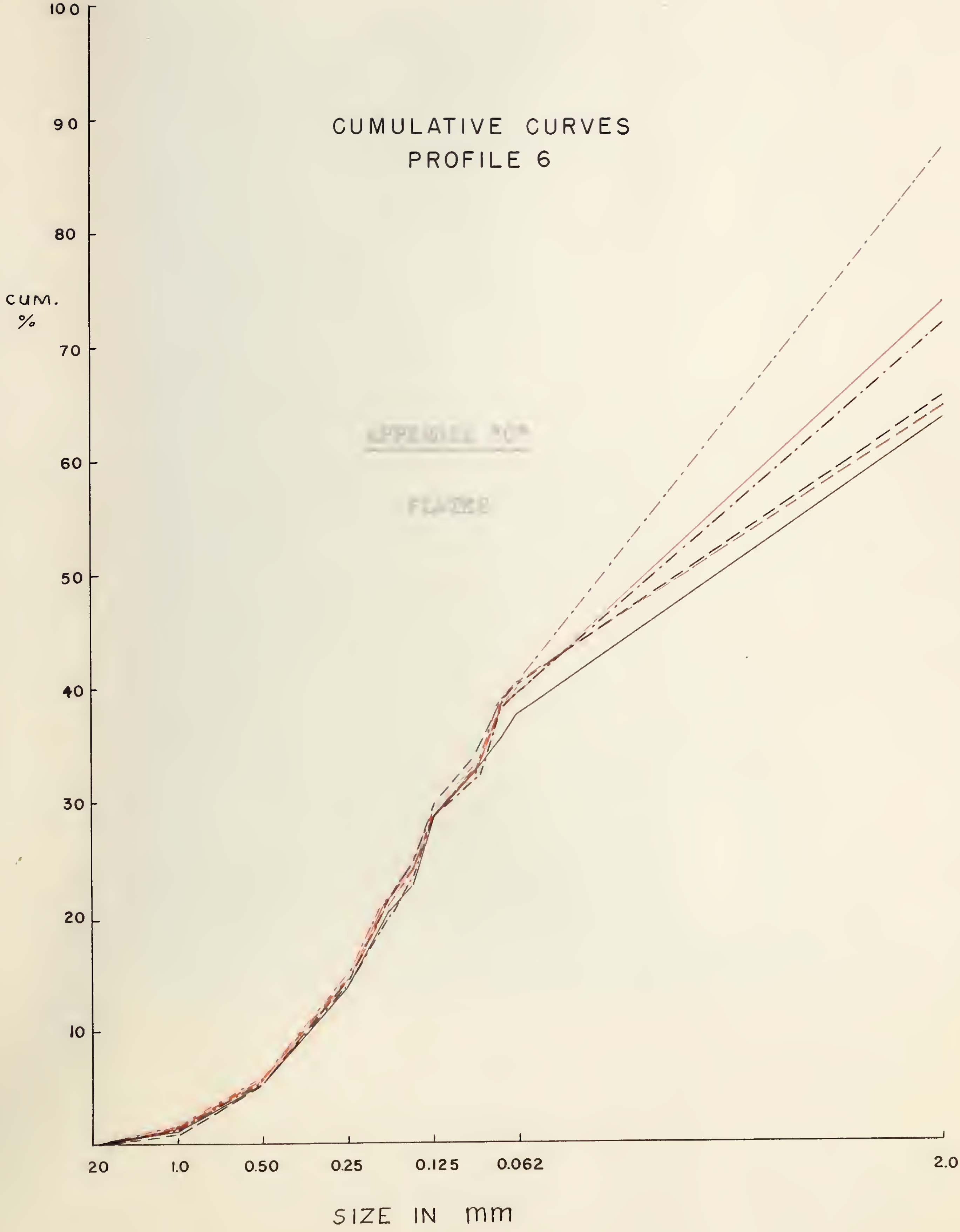
2.0
SIZE IN mm



CUMULATIVE CURVES
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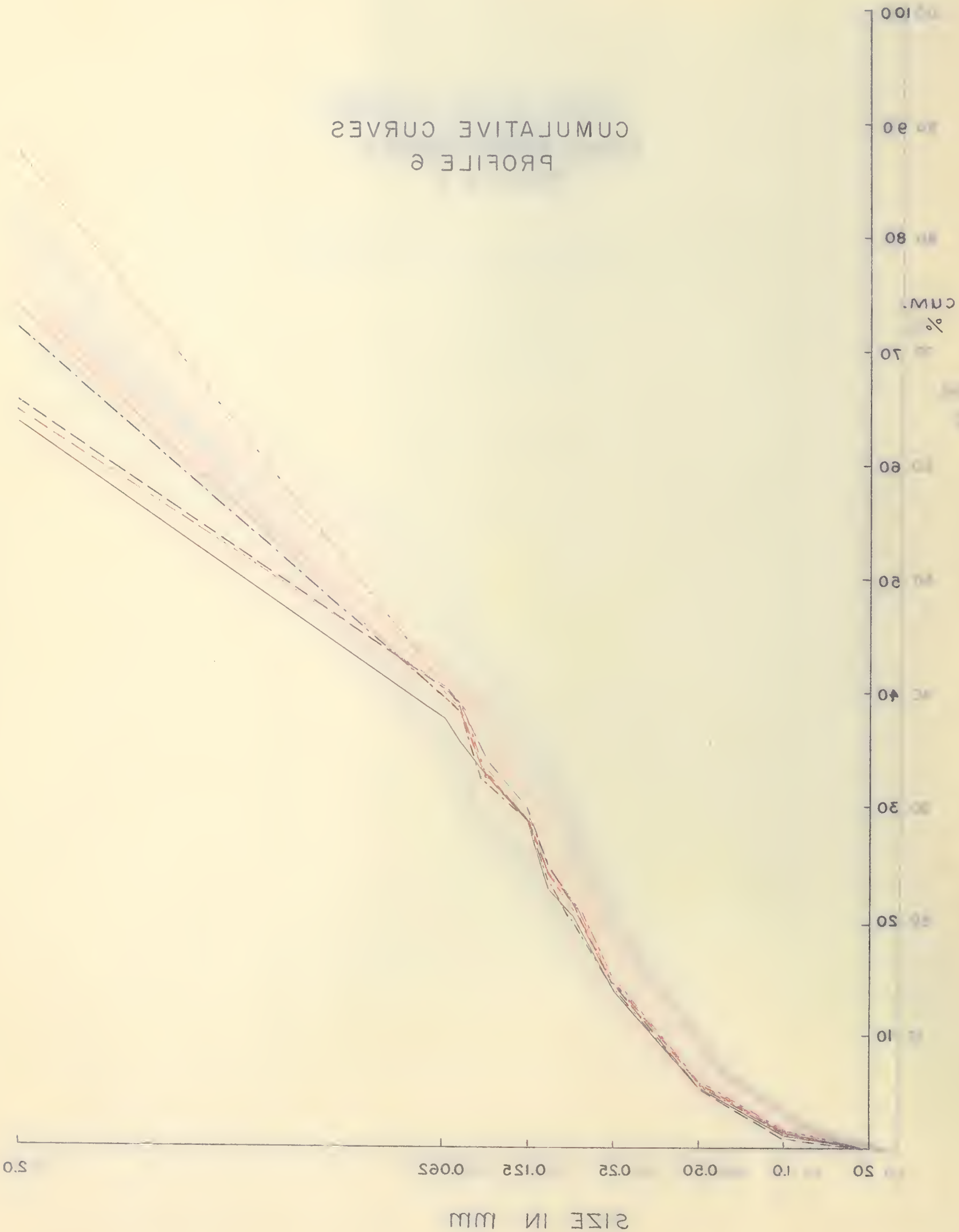
2.0
SIZE IN mm


CUMULATIVE CURVES
PROFILE 6
CUM. %
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40
30
20
10
20
1.0
0.50
0.25
0.125
0.062
2.0
SIZE IN MM

APPENDIX "C"

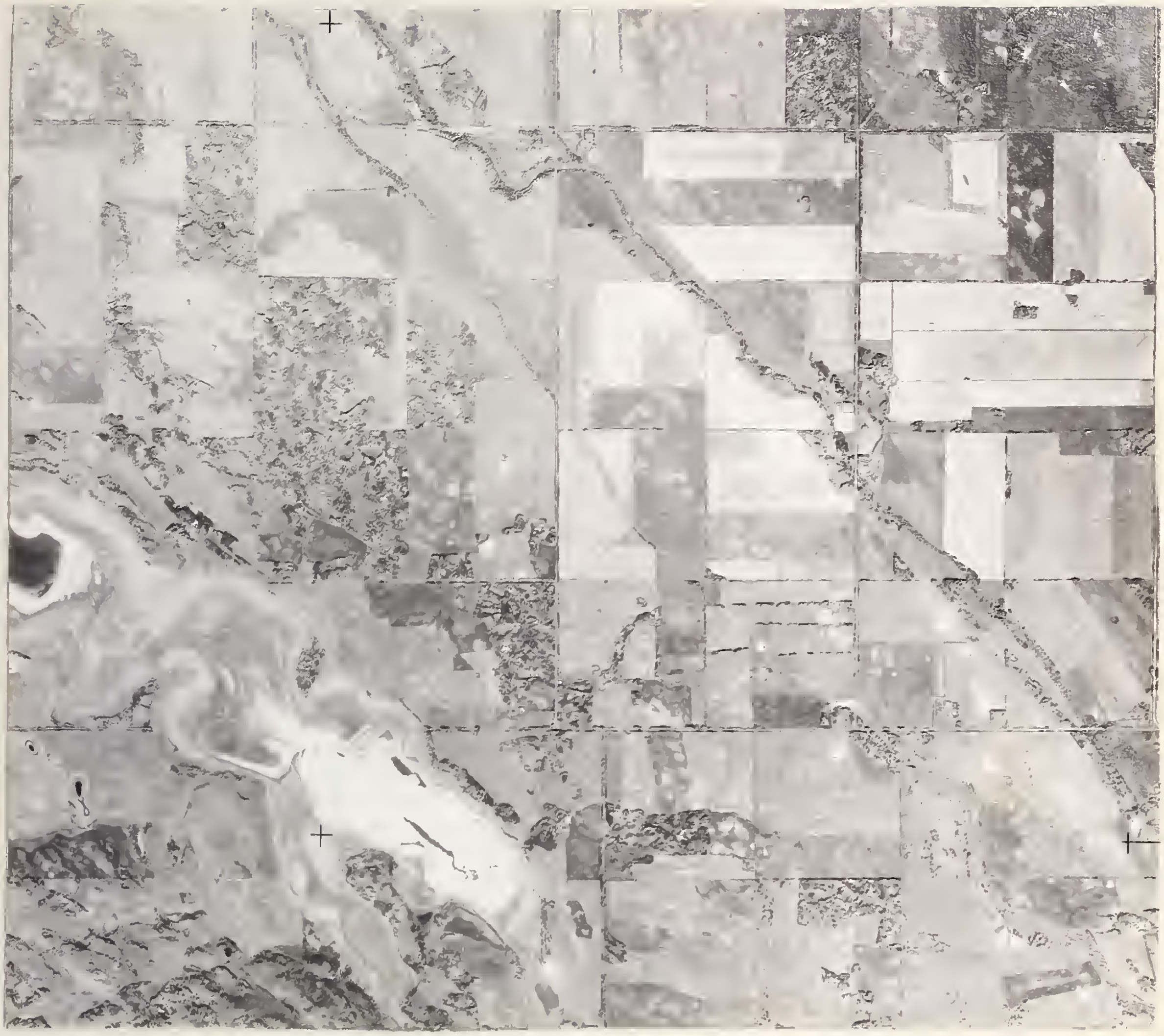
PLATES

PLATE 1

Aerial Photograph showing:
Coteau Ice Advance Boundary(solid line); Ice Block Ridges; Kettle Holes; Trends of the Viking and the Coteau Glaciations.
Location: Tp. 49, R. 2.

(Taken by the Dept. of Land and Forests, Gvt. of Alberta).

PLATE 2



Ridges and Coulees in the Northern Part of the Coteau Glaciated Region.

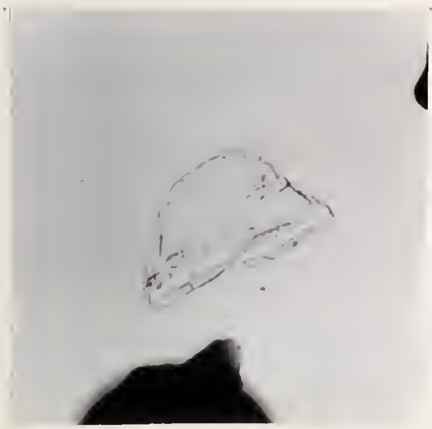
Location: Tp. 54, R. 5.

(Taken by the Dept. of Land and Forests, Gvt. of Alberta).

PLATE 3

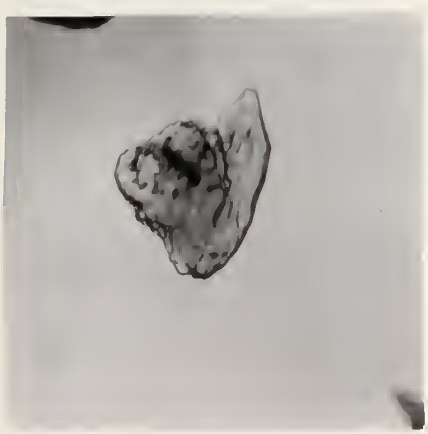
A. Hornblende
sample 4-6

B. Tremolite
sample 4-6



C. Mon. Pyroxene
sample 5-4

D. Augite
sample 1-5



E. Hypersthene
sample 4-5

F. Kyanite
sample 6-2

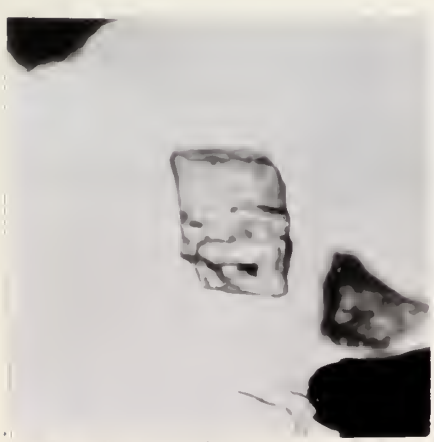
PLATE 4

A. Garnet
sample 3-6

B. Titanite
sample 5-4

C. Zircon
sample 6-2

D. Rutile
sample 6-1



E. Epidote
sample 1-5

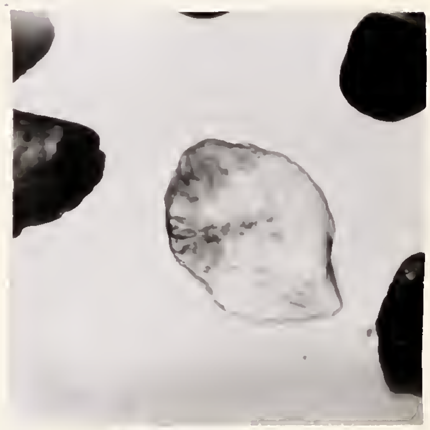
F. Staurolite
sample 3-4

PLATE 5

A. Tourmaline with secondary overgrowth from the Athabaska sandstone.

B. Tourmaline with rounded secondary overgrowth.
sample 6-4

C. Fresh Apatite
sample 3-6



D. Altered Apatite
sample 6-2

E. Tourmaline
sample 4-6

PLATE 6

A. Coteau Moraine (note uneven skyline).

Location: Tp. 55, R 2-west of the fourth meridian, Sec. 4, SW corner, looking east.

B. Flat Country between the Terminal Coteau Moraine and the Coteau Ice Advance Boundary.

Location: Tp. 52, R. 3-west of the fourth meridian, Sec. 20, NE quarter, looking north.

PLATE 7

A. Ice Block Ridge.

Location: Tp. 49, R. 2-west of the fourth meridian, Sec. 26, SE quarter.

B. Ice Block Ridge.

Location: Tp. 49, R. 1-west of the fourth meridian, Sec. 17, NE quarter.

PLATE 8

A. Roadcut showing contorted bedrock.

Location: Tp. 53, R. 6-west of the fourth meridian, Sec. 17, west boundary, ¼ of a mile south of the NW corner.

B. Same as above.
Close up of the fault.

PLATE 9

A. Coteau Moraine.
Roadcut showing the superglacial and the bottom moraine.

Location: Tp. 54, R. 2-west of the fourth meridian, Sec. 33, NW corner one third of a mile east.

B. Kettle Hole.

Location: Tp, 49, R. 2-west of the fourth meridian, Sec. 26, SW quarter.